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Criterions and Implementation of Polyherbal Nanoparticles

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ABSTRACT:

The synthesis, characteristics, and uses of nanoparticles (NPs), primarily derived from polyherbal formulations, including fullerenes, metal NPs, ceramic NPs, and polymeric NPs, are reviewed in this paper. Combine the therapeutic properties of different plants to generate unique and potent nanoparticles from polyherbal combinations. These nanoparticles are particularly attractive for use in the medical, electronics, and environmental cleaning industries because they have demonstrated promising qualities like increased stability, controlled release, and targeted distribution. Polyheral formulation-derived nanoparticles have been shown to have anti-diabetic properties and hold promise for the treatment of other chronic illnesses, including cancer and cardiovascular issues. These nanoparticles are suitable for a range of biological applications due to their low toxicity and strong biocompatibility, which have also been found.

Keywords: Nanoparticles; Metal Nps; Drug Delivery; Synthesis; Characterization

Introduction:

Nanotechnology has been studied since the 19th century, with significant advancements since Nobel Laureate Richard P. Feynman's 1959 lecture (Feynman, 1960). Nanoparticles (NPs) are particulate compounds with a minimum size of 100 nm (Laurent et al., 2010), available in various forms like 0D, 1D, 2D, or 3D. Nanoparticles and nanostructured materials are classified into four kinds depending on their chemical composition: organic, inorganic, carbon-based, and composite.

Traditional nanosized items help many countries' economies flourish. Based on porosity, nanomaterials may be divided into porous and non-porous materials. Porous materials have a less dense molecular structure, enabling airflow or atom, ion, and molecule absorption. Non-porous materials are denser, less absorbent, and allow for less airflow. Mesoporous nanomaterials with holes ranging in size from 2 to 50 nm in diameter are used to deliver therapeutic agents to tumour cells while minimising medication leakage into healthy cells (Barhoum et al., 2017). Because of their high porosity, surface functionality, and tiny pore diameters, these nanoparticles allow for regulated release and effective drug loading at the target region (Sawy et al., 2021). Additionally, the controlled release of therapeutic agents from mesoporous nanomaterials helps minimise possible side effects and improves the treatment's general effectiveness. Additionally, the surface functionality of these nanoparticles can be tailored to enhance their targeting capabilities, ensuring precise delivery to tumour cells while sparing healthy cells from unnecessary exposure to medication.

Researchers discovered that size can alter a substance's physiochemical qualities, such as its optical capabilities. Nanoparticles (NPs) have three layers: surface, shell, and core. Surface layers can be functionalized with small molecules, metal ions, surfactants, and polymers. Shell is chemically distinct from core, while core is the NP's centre component. These extraordinary properties have captivated researchers across various disciplines (Shin et al., 2016). Nanoparticles' special qualities have made them widely used in a variety of industries, including electronics, medicine, and environmental science. For instance, in medicine, nanoparticles have demonstrated great promise in targeted drug delivery systems, enabling more accurate and efficient disease treatment. Additionally, they are ideal candidates for applications in catalysis and sensors due to their small size and large surface area.

Types of nanoparticles:

Nanoparticles are classified into many categories based on their composition and features (Fig 1). Nanoparticles are varied, with distinct qualities and traits that make them suited for various applications. They are divided into four types: zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D). Zero-dimensional nanoparticles, like quantum dots, have all of their dimensions in the nanoscale range (Khan et al., 2019). One-dimensional nanoparticles, such as nanowires and tubes, have only one dimension in the nanoscale range. Two-dimensional nanoparticles, such as graphene, have two dimensions at the nanoscale. Dendrimers and liposomes have all three dimensions in the nanoscale range. 3D nanoparticles have a complex, highly ordered structure that makes them appropriate for drug delivery and nanomedicine. Because of their three-dimensional character, they have increased stability and structural integrity, making them appropriate for engineering and materials science applications (Schrand et al., 2010).

Metallic nanoparticles:

Metal nanoparticles, which are often formed of gold, silver, or platinum, are one popular variety. These metal nanoparticles have distinct optical and catalytic capabilities that make them helpful in industries such as electronics and medicine (Mody et al., 2010). Metallic nanoparticles are widely employed due to their superior conductivity and stability. They are commonly used in the manufacture of conductive inks, sensors, and catalysts. CuNPs are now replacing gold and silver nanoparticles as a promising contender for the future, but they are highly oxidant in nature, have a high melting point and electrical conductivity, have low electrochemical migration behaviour, are small in size, shape, and oxidation resistance, have a high surface/volume ratio, and are low in cost.

Furthermore, copper nanoparticles have attracted attention for their antibacterial capabilities, making them interesting candidates for medicinal applications such as wound healing and medication delivery systems (Table 1). Copper nanoparticles are tiny particles of copper that range in size from 1 to 100 nanometers. Previous research on the generation of CuNPs using Magnolia kobus leaf extract with spherical nanoparticles ranging in size from 50 to 250 nm has been published. Recent study indicates that proteins and metabolites, such as terpenoids and reducing sugars, play a role in the reduction of copper ions and the stability of synthesised CuNPs.They are widely used in electronics, catalysis, antimicrobial coatings, and even in the field of medicine for drug delivery systems. Understanding the synthesis methods and characteristics of copper nanoparticles is crucial for optimizing their performance and expanding their applications.

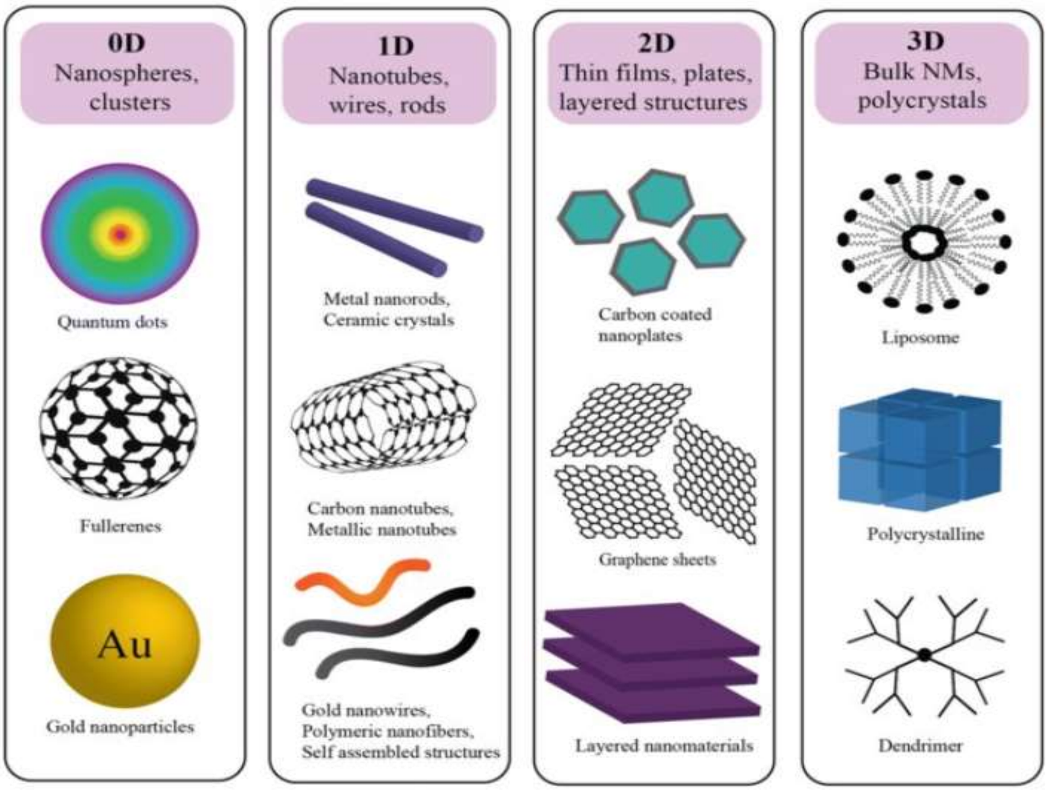

Fig 1: The relative dimensions of nanoparticles with examples of each category (Source: Tuang Yeow Poh et al., 2018)

Semiconductor nanoparticles:

Semiconductor nanoparticles are tiny particles with dimensions ranging from 1 to 100 nanometers made of semiconductor materials (Whitesides, 2005). These materials possess unique electronic and optical properties due to their small size, making them widely used in fields like electronics, optoelectronics, energy storage, catalysis, and biomedicine (Table 2). Factors affecting the synthesis of semiconductor nanoparticles include precursor materials, reaction temperature, pressure, reaction time, and the presence of catalysts or surfactants (Rawalekar & Mokari, 2013). Different synthesis methods can result in variations in nanoparticle size, shape, and composition. Quantum mechanical calculations and density functional theory (DFT) are commonly used to study the electronic properties of semiconductor nanoparticles, providing insights into energy levels, charge carrier dynamics, and optical properties, aiding in the design and optimization of nanoscale devices (Long et al., 2017).

Semiconductor nanoparticles such as quantum dots, nanowires, and nanorods have received a lot of attention due to their unique optical and electrical capabilities (Tamirat., 2017). These nanoparticles have been utilized in industries such as optoelectronics to increase the efficiency of solar cells and the performance of light-emitting diodes (LEDs). Furthermore, semiconductor nanoparticles are being investigated for their potential in biological imaging, allowing for high-resolution imaging of cells and tissues for diagnostic applications.

Table 1: Metallic nanomaterials types and their bioactivity

Metallic Nanoparticles	Bioactivity	References
Gold nanoparticles	Anticancer, Neuro reconstruction, Antiviral (HIV, Influenza),	Rai et al., 2016
Silver nanoparticles	Anticancer (Breast, Kidney and renal, Leukemia) Antibacterial (Bacillus subtilis, Staphylococcus aureus, Methicillin resistant coagulase) Antifungal (Candida sp.), Antiviral (Respiratory syncytial virus, Leishmania tropica, Herpes simplex virus)	Narducci, D., 2007, Yalcinkaya et al., 2016, Salama et al., 2021, Shahriary et al., 2018, Youssef et al.,2017
Copper nanoparticles	Antimicrobial (Bacillus subtilis, E. coli, S. aureus, Micrococcus luteus, Pseudomonas aeruginosa, Salmonella enterica, and Enterobactor aerogenes) Antifungal (Fusarium oxysporum and Phytophthora capsici) Antiviral (human influenza A (H1N1), avian influenza (H9N2) Anticancer (HeLa cells, MD A-MB-231 (human breast cancer cell lines), Caco-2 (human colon cancer cells), and HepG2 cells (Hepatic cancer cells) and Mcf-7 breast cancer cells. Wound healing activity, anti-inflammatory and anti-arthritic.	Harishchandra et al., 2020

Polymeric nanoparticles

Polymeric nanoparticles are microscopic particles made of polymers with a size range of 1 to 1000 nanometers (Win & Feng., 2005). They have unique properties due to their small size and large surface area-to-volume ratio. They are used in drug delivery systems, imaging agents, biosensors, and tissue engineering for drug encapsulation, targeting specific tissues, and controlled drug release (Table 3). Their small size bypasses biological barriers and efficient loading and release of therapeutic agents, enhancing drug efficacy and reducing side effects (Mallakpour & Behranvand., 2016).

Table 2: Semiconductor nanomaterials types and their bioactivity

Semiconductor Nanoparticles	Activity	References
Gold nanorods	Anticancer	Yi et al., 2020
Ag-In-Zn-S quantum dots	Anticancer (human alveolar basal epithelial cells)	Zhang et al., 2016
Cadmium telluride quantum dots	Bioimaging human bronchial epithelial cells	Das & Gavel., 2020
Multilayer carbon nanotubes	Anti-inflammatory	Debnath & Srivastava, (2021).
Single layer carbon nanotubes	Anticancer (head and neck squamous carcinoma)	Marcelo et al., 2015

Polymeric nanoparticles such as liposomes, dendrimers, and micelles have gotten a lot of interest because of their diverse characteristics and prospective uses in a variety of sectors. Liposomes, initially reported by Cohen and Bangham (1972) 40 years ago, are nanoparticles used to administer chemotherapy. They are vesicles with aqueous interiors and phospholipid bilayers that vary in size, content, and surface chemistry. Controlled medication administration, increased therapeutic agent stability, and targeted distribution to specific tissues or cells are all advantages of these nanoparticles. Furthermore, their biocompatibility and capacity to encapsulate both hydrophilic and hydrophobic medicines make them appealing.

Table 3: Polymeric nanomaterials types and their bioactivity

Polymeric Nanoparticles	Activity	References
Liposomes	Anti-inflammatory effect in a rat model of adjuvant-induced arthritis in vivo, Anticancer effect in mice xenografted with colon cancer cells in vivo, Free-radical scavengers, carcinogenic activity, inhibition of proinflammatory kinases,	Bhirde et al., 2010, Ruzycka-Ayoush et al., 2021, Tong et al., 2013
Poly-amido-amine dendrimers	Anticancer effect in methotrexate -sensitive and resistant human acute lymphoblastoid leukemia (CCRF-CEM) and Chinese hamster ovary (CHO) cells	Prabha & Raj., 2017
Poly-lactic acid	Anticancer effect in a mouse model of ovarian cancer in vivo.	Prabha & Raj., 2017
Chitosan	Therapeutic effect in a rat model of Alzheimer’s disease in vivo (preclinical study)	Luo et al., 2011

Nanoparticle synthesis:

Chemical Synthesis:

It employs a number of approaches (fig 2), including chemical, physical ad biological methods. Chemical methods are common approach for synthesizing nanoparticles. They include precipitation that involves mixing two or more precursor solutions to form a solid product, which is then further processed to obtain nanoparticles (Rane et al., 2018). Sol-gel synthesis involves the conversion of a liquid precursor into a gel, followed by drying and calcination to produce nanoparticles. The sol-gel technique is a wet-chemical method for producing high-quality metal-oxide nanostructures. A liquid precursor is converted into a sol, which is then transformed into a gel-like network structure (Dong et al., 2019). Precursors for this approach are often metal alkoxides. Metal oxide hydrolysis in water or alcohol, condensation, polycondensation, and ageing are all steps in the synthesis process. Parameters such as the kind of precursor, the rate of hydrolysis, the ageing duration, the pH, and the molar ratio of H2O to the precursor all influence the final product. The sol-gel technology is inexpensive and offers advantages such as homogeneous materials, low processing temperatures, and easy manufacturing of composites and complex nanostructures (Azadani et al., 2021). The method is inexpensive and has several advantages, including the ability to make composites and complex nanostructures.

Hydrothermal synthesis utilizes high-pressure and high-temperature conditions to promote the growth of nanoparticles from precursor solutions. Nanostructured materials are often created using hydrothermal and solvothermal methods (Schaf et al., 2004). Hydrothermal reactions occur in an aqueous media, whereas solvothermal reactions occur in a non-aqueous medium. In closed systems, both tactics are often utilised. The microwave-assisted hydrothermal technique, which combines hydrothermal and microwave technologies, has garnered interest in the field of nanomaterial engineering (Shi et al., 2014). These methods may be used to construct a wide range of nano-geometries, including nanowires, nanorods, nanosheets, and nanospheres. These technologies allow researchers to precisely manipulate the size, shape, and composition of nanoparticles, allowing them to tune their characteristics for specific purposes (Rehan et al., 2019).

Physical synthesis:

In the physical manufacturing of nanoparticles, ball milling and lithography methods have been widely used. Ball milling is the process of grinding and combining materials to reduce them to nanoscale dimensions, whereas lithography uses masks and etching procedures to create patterns on nanoscale surfaces (Kumar & Kumbhat, 2016).. These physical techniques provide excellent control over particle size and shape, making them ideal for applications requiring consistency and accuracy. Mechanical milling is used to manufacture aluminium alloys, wear-resistant spray coatings, and a variety of nanocomposite materials. Carbon nanoparticles that have been ball-milled are distinctive and beneficial for environmental remediation, energy storage, and energy conversion. Ball-milled carbon nanomaterials are a unique kind of nanomaterial that may be used for environmental cleanup, energy storage, and energy conversion (Lyu et al., 2017).

Another frequent physical method for nanoparticle genesis is laser ablation. A laser beam is used to vaporise a target substance, which subsequently condenses into nanoparticles (Abdel-Haleem et al., 2019). Laser ablation synthesis is a green method for generating noble metal nanoparticles that does not require the use of any stabilising agents or solvents. This method produces a wide variety of nanomaterials, including metals, carbon, oxide composites, and ceramics. Pulsed laser ablation in liquids is an intriguing method for creating monodisperse colloidal nanoparticle solutions without the need of surfactants or ligands.

Nanoparticle parameters such as average size and distribution may be controlled by varying fluence, wavelength, and laser salt addition (Sportelli et al., 2016). The wavelength and fluence of the pulsed laser have a substantial effect on the sizes of as-synthesised Pd nanoparticles (zhao et al., 2014). This technology provides for exact control over the size and content of the nanoparticles generated, making it suited for medication administration and catalytic applications. Furthermore, laser ablation in a liquid environment allows for the production of nanoparticles with unique characteristics and surface changes. These physical therapies are really effective.

Biological synthesis:

Biological synthesis of nanoparticles is a process that involves the use of living organisms, such as bacteria or plants, to produce nanoparticles (Arya, 2010). This method offers several advantages over traditional chemical synthesis, including lower cost, environmentally friendly production, and the ability to produce nanoparticles with unique properties. Additionally, biological synthesis allows for precise control over the size, shape, and composition of the nanoparticles produced (Gericke & Pinches, 2006).

Furthermore, breakthroughs in nanotechnology have led in the creation of novel synthesis approaches such as green synthesis, which uses environmentally friendly materials and procedures to create nanoparticles with reduced toxicity and improved biocompatibility (Jahangirian et al., 2017). For example, researchers have used bacteria to produce silver nanoparticles, which have antimicrobial properties (Duran et al., 2016). By controlling the growth conditions of the bacteria, they were able to control the size and shape of the nanoparticles, resulting in smaller particles with increased surface area for enhanced antimicrobial activity. This biological synthesis method not only offers a cost-effective and sustainable approach to producing silver nanoparticles but also allows for tailoring their properties for specific applications in medicine or consumer products.

Microorganisms or plants are utilised as bioreactors to create nanoparticles through their metabolic processes. This technology provides a sustainable and environmentally friendly alternative to standard chemical processes, allowing for the creation of nanoparticles with distinct features (Meunier et al., 2010).

While chemical approaches enable flexibility in nanoparticle synthesis, biological approaches using microorganisms and plants provide a sustainable and environmentally friendly alternative that allows for the manufacture of nanoparticles with unique features. Furthermore, using plants as bioreactors for nanoparticle manufacturing has the added benefit of exploiting of their inherent metabolic processes. This indicates that nanoparticles created using this process are more likely to be biocompatible and less harmful than those created chemically. Furthermore, using plants as bioreactors allows for the production of vast amounts of nanoparticles, making it a cost-effective and scalable approach to nanoparticle synthesis (Makarov et al., 2014).

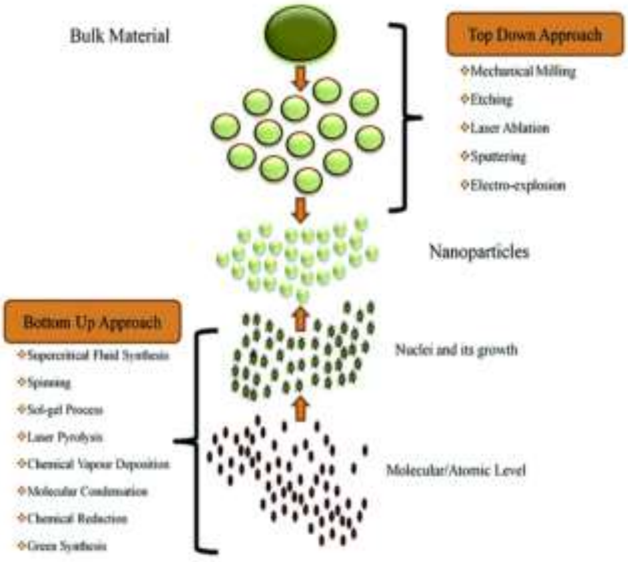

Fig 2: Top-down and Bottom-up approaches for synthesis of nanoparticles (Source: Khanna et al., 2019)

Nanoparticle Characterization:

Nanoparticle characterization entails analysing and comprehending their physical, chemical, and structural characteristics at the nanoscale (Table 4). This procedure is critical for identifying the size, shape, surface area, content, and surface chemistry of the particles (Grainger & Castner, 2008). Nanoparticle size and form may be determined using techniques such as electron microscopy, dynamic light scattering, and atomic force microscopy. Brunauer-Emmett-Teller (BET) analysis and X-ray photoelectron spectroscopy (XPS) are used to determine the surface area and composition of nanoparticles.

X-ray diffraction (XPS) is a surface-sensitive method used in depth profiling research to determine the composition and variation in composition with depth. It is based on fundamental spectroscopic principles and involves plotting electron numbers on the Y-axis against binding energy (eV) on the X-axis. Each element has its own fingerprint-binding energy value, resulting in unique XPS peaks. In a study by Lykhach et al (2017)., they found that for every 10 Pt atoms, only one electron is elated from the NPs to the CeO2 support. The Debye Scherer formula offers a basic sense of particle size for distinguishing single and multiphase nanoparticles (Emery et al., 2016; Ullah et al., 2017). Obtaining and quantifying structural characteristics for smaller NPs, on the other hand, might be difficult. Furthermore, NPs with amorphous properties and varying interatomic lengths can have an effect on XRD diffractograms. A proper comparison of bimetallic NP diffractograms with monometallic NPs and their physical mixes is required for reliable information. The easiest technique to get good contrast is to compare computer-simulated structural models to observed XRD spectra (Ingham, 2015).

Surface chemistry may also be studied using methods such as Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy. These investigations give useful information for understanding the behaviour of nanoparticles and their prospective uses in disciplines such as medicine and environmental research (Movasaghi et al., 2008). For example, understanding the surface chemistry of nanoparticles can contribute to the creation of more efficient drug delivery systems in medicine, while it can aid in analysing the influence of nanoparticles on ecosystems in environmental science.

Microscopy techniques are critical in supplementing the data gained from spectroscopic studies. Nanoparticles may be visualised and characterised at the nanoscale using techniques such as transmission electron microscopy (TEM) and scanning electron microscopy (SEM). Researchers may acquire a thorough knowledge of the structure, content, and behaviour of nanoparticles by combining spectroscopy and microscopy, allowing breakthroughs in domains ranging from materials science to nanotechnology (Avasare et al., 2015). SEM or TEM is a technique for analysing single nanoparticles (NPs) by focussing electron beams on component elements. These NPs release distinctive energy X-rays that are proportional to the element concentration. This approach is commonly used by researchers to supplement SEM and other techniques for validating components in produced materials (Iqbal et al., 2016).

Ellipsometry**,** and atomic force microscopy are commonly used techniques to characterize the surface properties of nanoparticles. These techniques can provide information about the composition, thickness, and roughness of the nanoparticle surface, which are important factors that influence their interactions with other molecules or materials (Kasper et al., 2019). By understanding the surface characteristics, researchers can tailor the nanoparticles for specific applications such as drug delivery or catalysis.

. Another approach often used to analyse nanoparticles is dynamic light scattering (DLS). DLS is a technique that studies the interaction of light with nanoparticles, providing information about their size, shape, composition, and optical properties. This technique has applications in materials science, biotechnology, and environmental monitoring, among others (Niemeyer, 2001). DLS examines light scattering patterns to determine particle size distribution, hydrodynamic radius, and nanoparticle stability. Understanding the properties of nanoparticles is critical for developing new materials with improved performance and functionality. This knowledge can be used to optimize materials for uses such as electronics, energy storage, and catalysis. DLS is also important in biotechnology, where nanoparticles are increasingly being used for drug delivery and imaging.

Table 4: Characterization of Nanoparticles

Characteristics	**Solid**	**Liquid**
Size	Electron microscope and laser diffraction for bulk samples	Photon correlation spectroscopy and centrifugation
Surface area	BET Isotherm	Simple titration and NMR experiments
Composition	XPS and Chemical digestion followed by wet chemical analysis for bulk samples.	Chemical digestion for mass spectrometry, atomic emission spectroscopy and ion chromatography
Surface morphology	Image analysis of electron micrographs	Deposition onto a surface for electron microscopy
Surface charge	Zeta potential	Zeta potential
Crystallography	Powder X-ray or neutron diffraction	-

BET – Brunauer–Emmett–Teller model, NMR – Nuclear Magnetic Resonance Spectroscopy, XPS – X-ray Photoelectron Spectroscopy (Anu mary & Saravanakumar, 2017).

Nanoparticle applications:

Nanoparticle applications have grown rapidly in recent years, including medicine, electronics, and environmental science. These tiny particles, which are typically less than 100 nanometers in size, have unique properties that make them extremely versatile and useful in a variety of applications. One of the most significant advances in nanoparticle research has been in medicine, where these particles have demonstrated great promise in drug delivery, diagnostics, and imaging.It includes drug delivery systems in which nanoparticles encapsulate and transport medications to specific target areas in the body. Nanoparticles are also used in environmental remediation, such as removing contaminants from water and air. They could be used in electronics, where nanoparticles can improve conductivity and reduce energy consumption.

Medicine and Healthcare:

Nanoparticles are used in medicine and healthcare in a variety of ways, including targeted cancer treatment, in which nanoparticles transport medications specifically to tumour cells while causing minimal harm to healthy organs. Nanoparticles are also being researched for diagnostic reasons, such as imaging tools for early illness detection. Furthermore, nanoparticles have shown potential in regenerative medicine by stimulating tissue regeneration and promoting repair in wounded or diseased tissues (Zhang & Webster, 2009).

Nanoparticles provide a distinct advantage in drug delivery systems, which are continually changing. Their compact size enables efficient transit through the body and precise targeting of specific target locations. Furthermore, nanoparticles may be programmed to release medications in a regulated manner, ensuring maximal therapeutic benefits while minimising negative effects. This has the potential to change the way illnesses are treated and enhance patient outcomes.

Nanoparticle-based medication delivery systems have shown considerable potential in cancer therapy. It is feasible to selectively target cancer cells while protecting healthy tissues from the damaging effects of chemotherapy medications by encapsulating them into nanoparticles (Vahed et al., 2017). This customised strategy not only improves treatment efficacy but also decreases the unpleasant side effects often associated with standard cancer medicines. As research in this sector advances, nanoparticle-based drug delivery systems have enormous potential for revolutionising cancer therapy and increasing patient quality of life.

The use of nanoparticles in drug delivery has significantly improved the medical field, reducing drug consumption and side effects. This method also enables tissue engineering (Hasan et al., 2018), which can be used to replace traditional treatments such as artificial implants and organ transplants (Wang et al., 2021). Gold, a common Ayurvedic ingredient, is used to improve memory and in medical preparations to improve mental fitness. Gold nanoparticles have shown promise in identifying and killing cancer cells while causing minimal harm to healthy cells (Cai et al., 2008; Sztandera et al., 2018). Due to its high biocompatibility and ability to absorb and convert light into heat, gold nanoparticle-mediated photothermal therapy is an ideal candidate.

Electronics and Energy:

Nanoparticles have numerous applications in electronics, energy, biotechnology, and energy storage. They are found in solar cells, sensors, batteries, and fuel cells, as well as in environmental remediation, imaging, and diagnostics (Mobasser & Firoozi, 2016). Nanoparticles' small size and unique properties make them highly efficient catalysts for chemical reactions, opening up possibilities for sustainable and environmentally friendly industrial processes.

They also have the potential to revolutionise energy storage, particularly in batteries and supercapacitors. By incorporating nanoparticles into battery materials, researchers can enhance their energy storage capacity and performance (Kong et al., 2020).

Additionally, nanoparticles have been used in the development of supercapacitors, which have the potential to revolutionise energy storage due to their high power density and fast charging capabilities. The utilisation of nanoparticles for renewable energy is the subject of much investigation. Higher light and UV absorption with extremely low reflection coatings in solar cells has significantly enhanced their efficiency (Hanaei et al., 2016). Some nanoparticles' hydrophobicity has resulted in self-cleaning solar panels. Certain nanoparticles with high thermal conductivity and heat absorption capacity are used to cover boilers and solar concentrators to increase thermal efficiency. These advancements in nanoparticle technology have the potential to significantly impact the renewable energy sector and contribute to the development of more efficient and sustainable energy storage solutions.

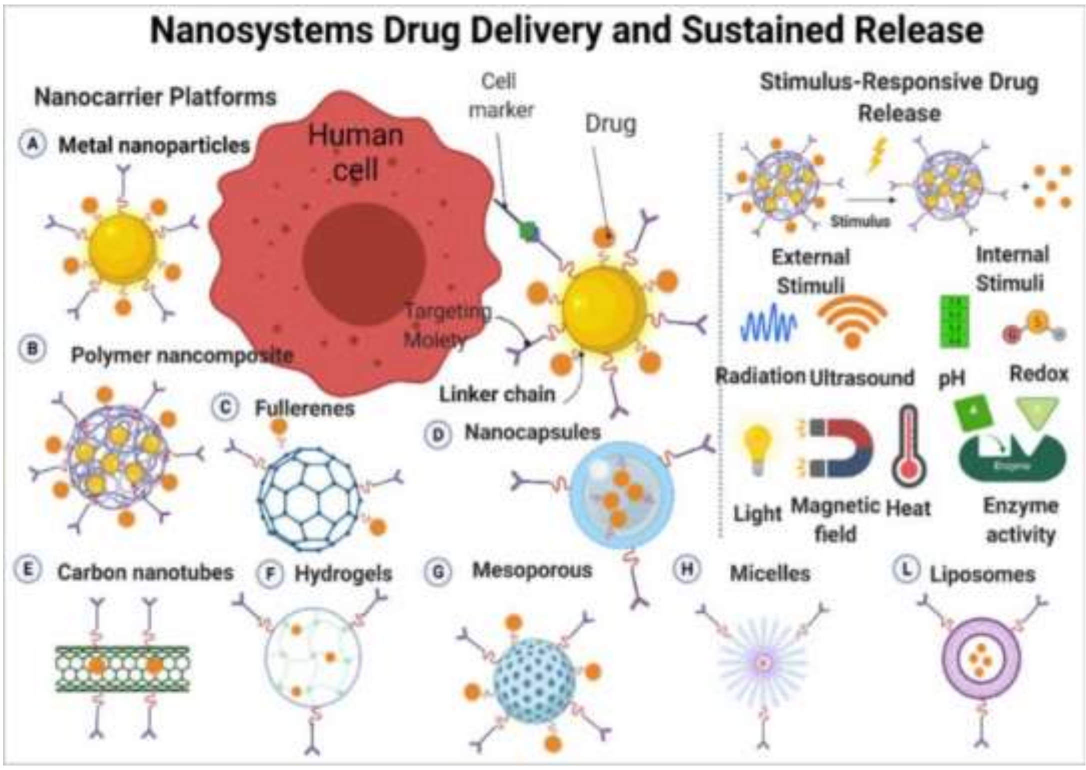

Fig 5: Nanomaterial for precise drug delivery through biological membranes (Source: Vancha Harish et al., 2022 Copyright © 2022 Licensee MDPI, Basel, Switzerland).

Environmental remediation:

Nanoparticles have unique physical and chemical properties, making them an excellent choice for environmental remediation and improving the performance of the renewable energy sector. For over a decade, these nanoparticles have been used to treat and decontaminate air, water, and soil, providing in situ treatment without the need for groundwater pumping or excavation (Ossai et al., 2020). They are injected into the desired location and carried along the groundwater flow, where they decontaminate water via redox reactions.

Nanoparticles are also used to disinfect, purify, and desalinate surface water, removing heavy metals, pathogens, and organic contaminants. Oil spills are a major global issue, and nanoparticles are used to clean them up, resulting in lower costs, higher efficiency, and a smaller amount of treatment required (Dhaka & Chattopadhyay, 2021). Nanofiltration is a type of membrane filtration system that is commonly used in the food and dairy industries. Soil contamination is also becoming a major issue, and nanoparticles are being used to clean or treat it by injecting nanoparticles into particular locations for contamination with heavy metals and toxic industrial waste (Azimi et al., 2017).

Nanoparticles are used as small catalysts in gaseous actions, particularly in industrial stacks, to reduce levels of contaminants or completely remove them, thereby reducing air pollution. Extensive research on the use of nanoparticles for renewable energy is being conducted, with higher light and UV absorption and low reflection coatings in solar cells improving efficiency (Adak et al., 2022). Some nanoparticles' hydrophobic properties have resulted in self-cleaning solar cells, and high temperature conductivity and heat absorption abilities are used to coat heating systems and solar concentrators, improving their thermal efficiency even further.

Challenges and Future Directions of nanoparticles:

Nanoparticles face several challenges in terms of their potential environmental and health impacts. As they become more widely used in various industries, it is crucial to thoroughly understand their behavior and potential risks to human health and the environment. Additionally, future research should focus on developing sustainable methods for nanoparticle synthesis and disposal, as well as exploring their applications in fields such as medicine, electronics, and energy storage. By studying the behavior of nanoparticles, scientists can develop guidelines and regulations to ensure their safe use and minimize any harmful effects. It is also important to assess the long-term environmental impacts of nanoparticle accumulation and find ways to mitigate their potential damage. Furthermore, exploring the potential applications of nanoparticles in medicine could lead to breakthroughs in targeted drug delivery and more effective treatments for various diseases. Overall, continued research and responsible use of nanoparticles will be crucial in maximizing their benefits while minimizing their risks.

Conclusion:

Nanotechnology is transforming daily life by enhancing the performance and efficiency of ordinary things, promoting a clean environment, and delivering clean renewable energy for a more sustainable future. Nanotechnology is being investigated for novel uses to boost efficiency and decrease costs, with major investment in research and development. Nanomaterials are suited for biomedical applications such as bioimaging, cosmetics, tissue-engineered scaffolds, drug delivery systems, biosensors, wound healing, and the food and agricultural sectors due to their superior physical, chemical, and biological properties. Nanomaterials have been employed in the creation of biosensors, targeted medication delivery, and tissue reengineering. Fluorescence nanoparticles are also being examined for their in vivo and in vitro destiny, as well as their antibacterial capabilities. Overall, nanotechnology has a bright future because of its efficiency and environmental friendliness.

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